Composites Part B 109 (2017) 45–52

Contents lists available at ScienceDirect

Composites Part B

journal homepage: www.elsevier.com/locate/compositesb

Structure and physical-mechanical properties related to comfort of flexible polyurethane foams for mattress and effects of artificial weathering

Paola Scarfato*, Luciano Di Maio, Loredana Incarnato

Department of Industrial Engineering, University of Salerno - Via Giovanni Paolo II, 132 – 84084, Fisciano, SA, Italy

ARTICLE INFO

Article history:
Received 26 July 2016
Received in revised form
21 September 2016
Accepted 16 October 2016
Available online 18 October 2016

Keywords:
Polyurethane
Flexible foam
Artificial weathering
Comfort

ABSTRACT

The aim of the work was to test three flexible polyurethane foams for mattress for comfort and durability. In particular, they were investigated the effects of foam composition and cell architecture on some physical-mechanical properties of interest for bedding applications and related to foam comfort levels (i.e. surface firmness, hysteresis loss and resistance to bottoming out), and their changes after artificial weathering due to moisture and temperature.

The results demonstrated that all the three foams have open cell morphology and similar cell structure, with average cell diameters ranging from 430 to 510 micron and wide cell size distribution. As a consequence, they also show comparable water vapor transport behavior. On the contrary, their mechanical response, in terms of hysteresis loss, surface firmness and resistance to bottoming out, was found strongly dependent on their chemical structure and molecular mobility, as inferred from infrared spectroscopy analysis. During accelerated weathering all the foams undergo oxidations that affected their comfort factors in static conditions, giving a progressive lowering of hysteresis loss, surface firmness and resistance to bottoming out, particularly for the two foams having lower crosslinking level and thus slow recovery rate after compression.

1. Introduction

Polyurethane (PU) foams are a class of highly versatile cellular polymers, made up of a solid and gas phase mixed together, industrially produced by polyaddition of polyisocyanates and macropolyols, whereby urethane groups are formed in the polymer backbone (Fig. 1).

Depending on the chemical nature of the reagent molecules, the formulation composition and the reaction conditions, thermoplastic, elastomeric or thermoset PU foams with different morphologies and geometries of their microstructure, and properties tailored for specific applicative fields (building and constructions, transportation, furniture and bedding, packaging, etc.), can be obtained [1]. Among them, open cell flexible PU foams, having low-resilience or 'viscoelastic' behavior, are particularly favorable for applications in several sectors, e.g. bedding, automotive seating, footwear, etc., where high foam comfort levels, as perceived by users, and consistent performance of the foam over its lifetime are required.

Many authors have devoted considerable research efforts on the experimental and theoretical characterization of polymeric foams with the aim to provide insight on the physical-mechanical properties related to the foam architecture and comfort and on their changes during the material normal use, in order to obtain quantifiable variables suitable to measure the foam comfort from the mechanical point of view [2–11]. However, the results are far from conclusive, even because the weathering effects due to environmental agents (such as moisture and temperature) on comfort are only rarely considered. Therefore, more work is still necessary to understand the complex relationships among foam composition, structure, final properties and durability, needful for the design of foam systems able to ensure high comfort levels to users and for the assessment of their lifetime.

In this context, in this work three different flexible PU foams, used as layers in a mattress construction, were analyzed in order to investigate the influence of their composition and architecture (apparent density, porosity, cellular structure) on some physical-

* Corresponding author.
E-mail addresses: pscarfato@unisa.it (P. Scarfato), ldimaio@unisa.it (L. Di Maio), lincarnato@unisa.it (L. Incarnato).

http://dx.doi.org/10.1016/j.compositesb.2016.10.041
1359-8368/

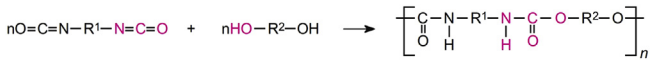

Fig. 1. Urethane linkage formation by reaction between a diisocyanate with a diol.

mechanical properties related to foam comfort levels (i.e. water vapor permeability, resilience and compression mechanical properties). In particular, with the aim to improve the understanding of factors affecting the foam mechanical comfort in static conditions, stress–strain measurements in 25% and 65% compression and hysteresis tests have been carried out that allowed to highlight the differences in terms of recovery rate, sag factor and hysteresis loss of the analyzed foams. Moreover, since polymers and polymer composites can undergo to some degradation by several environmental agents [12–15], the effects of artificial weathering due to temperature and moisture of the three foams were considered. In particular, accelerated weathering tests, by exposure in a climatic chamber at 50 °C and 95%RH (ASTM D3574) for different time intervals (5, 10 and 15 days), were carried out, in order to investigate the changes in the foam chemical structure and morphology and their effects on the factors affecting the foam comfort.

2. Materials and methods

The study was performed on three commercial flexible polyurethane foams, having different viscoelastic behavior, used as internal components in multi-layer foam mattress fabrication. The materials, commercially named FF60N, VISCOPUR and AP35B, and delivered as of 60 kg/m^3, 45 kg/m^3 and 35 kg/m^3 density, respectively, were kindly supplied by Rinaldi Group s.r.l. (Italy). The foam nomenclature, their position in the mattress structure and their nominal density are reported in Table 1.

All the specimens for the analyses were cut from the blocks of the foamed materials.

The apparent density tests were carried out in accordance with ASTM 3574-03 test A. The value of the apparent density was calculated as the average mass/volume ratio of three regular shaped samples having volume not less than 1000 mm^3.

The cellular structure of the foam samples was evaluated using an optical microscope with video channel. Three micrographs of each foam structure were taken in order to perform the analysis on the basis of more than one hundred cells. The cell average sizes were evaluated analyzing each photo with the IMAGEJ software.

Extraction experiments were carried out on foam samples to compare the level of cross-linking (gel fraction). Small pieces of foams (20 × 20 × 10 mm^3) were weighed and extracted in N,N-dimethylformamide (DMF) at room temperature for 24 h. The solvent was changed every 8 h. Finally, the solvent was vaporized under vacuum until a stable weight of the specimens was achieved. The percentage of the insoluble portion of the initial sample gave the gel fraction [16].

Equilibrium moisture content was determined as difference between the weight of the foam at equilibrium at 25 °C and R.H. = 50% and the weight of the foam dried under vacuum at 105 °C for 24 h.

Fourier transform infrared (FT-IR) spectroscopy was performed using a Nexus ThermoNicolet spectrometer (Thermo Scientific, USA) equipped with a SmartPerformer accessory for ATR analyses. The samples were scanned 64 times with a resolution of 2 cm^{-1} over the wavenumbers range from 4000 to 650 cm^{-1}. The spectral analyses were performed using an Omnic spectra analyzer.

The water vapor transport behavior through the foam materials was investigated according to the ASTM E 96-93 — Standard Test Methods of Water Vapor Transmission of Materials – Dry Cup Method. About 300 g of silica gel was placed in a glass crystalizing dish, 150 mm diameter and 75 mm deep. The edges of the test specimen, with the same diameter as the dish, were sealed and then mounted air-tight on the dish with silicone rubber. The assembly was then placed in a chamber at T = 25 °C and relative humidity R.H. = 75%. The mass gain of the assembly was recorded periodically and the water vapor transmission (WVT) rate and water vapor permeability (P) were calculated as:

$$WVT = \frac{M}{t \cdot A} \tag{1}$$

where: M is the mass (g) of absorbed water at time t (h) and A (m^2) is the surface of the exposed foam section; and:

$$P = \frac{WVT \cdot h}{P_{(H_2O)} \cdot \Delta(\text{R.H.})} \tag{2}$$

where: h(m) is the sample thickness, P(H_2O) = 23.76 mmHg is the water's saturated vapor pressure at 25 °C and Δ(R.H.) = 0.75 is the difference between the R.H. values (expressed as a fraction) at the two sides of the foam sample [17]. Three specimens of each sample were used for the measurements and the average data were reported.

Differential scanning calorimetry (DSC) measurements were performed with a Mettler DSC 822 calorimeter (Mettler-Toledo, USA). The thermograms of 8–12 mg samples, sealed in standard aluminum pans, were obtained by heating the materials at 50 °C/min from −120 °C to 220 °C under a nitrogen gas purge.

The mechanical hysteresis loss (HL) (ASTM D3574-03 X6) of the samples was measured using 200 × 200 × 50 mm^3 foam samples in the compression mode on a SANS CMT 6000 Series testing machine (MTS, China). Each sample was preconditioned by deforming it twice to 75% of its initial thickness, at a rate of 240 mm/min, after which they were allowed to relax for 6 min, without any applied load. After the samples were compressed to 75% of their initial thickness at 50 mm/min, then the compression force was removed at 50 mm/min until the platen fully returned. The HL was calculated as:

$$HL = \frac{\text{Loading Energy} - \text{Unloading Energy}}{\text{Loading Energy}} \times 100 \tag{3}$$

where the Loading Energy is the energy (i.e. the area under the

Table 1
Sample nomenclature and density.

Sample	Mattress structure		Nominal density [kg/m^3]
FF60N	Top comfort layer		60
VISCOPUR	Middle comfort layer		45
AP35B	Bottom core layer		35